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U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 243.

A. C. TRUE, Director.

Cop. 3

LAND DRAINAGE BY MEANS OF PUMPS.

BY

S. M. WOODWARD,
Drainage Engineer, Drainage Investigations.

PREPARED UNDER THE DIRECTION OF
C. G. ELLIOTT,
Chief of Drainage Investigations.

WASHINGTON:
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., January 27, 1911.

Sir: I have the honor to transmit herewith a manuscript on Land Drainage by Means of Pumps, by S. M. Woodward, professor of hydraulics, Iowa State University. This bulletin is based upon information obtained from numerous sources, among which are: Inspections of and reports upon the drainage pumping districts in Illinois, made by John T. Stewart in 1904, by G. A. Griffin in 1908, and by S. M. Woodward in 1910, all of whom have been connected with the staff of this office; data and descriptions furnished by various landowners and district officials, especially by Mr. Jacob A. Harman, of Peoria, Ill., whose long and intimate detailed acquaintance with drainage work and conditions on the Illinois River has especially qualified him to furnish extensive and exact information relating to that region, and various publications of this office.

This subject has come to be one of great importance in the development of large tracts of overflow and swamp lands and one upon which heretofore there has been little published information. I therefore recommend that this manuscript be published as Bulletin No. 243 of this office.

Very respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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LAND DRAINAGE BY MEANS OF PUMPS.

INTRODUCTION.

The drainage of low-lying lands by the use of pumping machinery to lift the drainage water over levees into adjacent streams or other drainage channels is a recent development in this country. Along the banks of many of our larger interior rivers considerable areas of bottom land are subject to overflow from the adjacent streams during the high water occurring usually with great regularity throughout the spring and early summer months. Such lands in their native state do not become dry enough to be subject to ordinary cultural operations until well toward the middle of the summer, and hence can not generally be used for growing ordinary crops. They can, therefore, in this natural condition be used for nothing but pasture and have accordingly but little agricultural value.

Similarly, extensive marshy areas along our coasts may be for a part of the time above water level, but are subject to overflow at high tide, especially during spring tides and when the river channels which form their natural drainage outlets are in flood. All such low lands are, in general, formed by alluvial deposit and possess a high degree of fertility when relieved of their excess of water and changed from their original saturated condition to a degree of moisture content suitable for ordinary dry-land crops.

As a physical proposition it is possible to reclaim all such areas for agriculture by first constructing levees to keep them from being overflowed, and then, where necessary, by installing pumping plants to pump out from the interior of the district the excess rainfall and such water as may seep through or under the levees in injurious amounts. But as such work is expensive both for the first construction and for its subsequent maintenance and operation, the really difficult and fundamental question for the landowner is, whether the value of the land, after its reclamation, will be sufficient to justify the expenditures necessary to carry out the work.

So long as there exists in a locality any unoccupied or unutilized higher land suitable for agriculture there is little demand for the use of lands lying so low as to require drainage by pumps. But the present high price of agricultural land justifies a heavy expenditure for the conversion to a productive state of areas formerly considered almost valueless, especially in those regions where agricultural land values are particularly high, either on account of unusually favorable natural conditions or the proximity of large centers of population.

EFFECTIVENESS OF DRAINAGE RECLAMATION.

Some areas are so favorably situated that, when once protected by levees from inundation, satisfactory interior drainage without the use of pumps may be secured by a natural or gravity flow of their drainage waters, either through sluice gates or through ditches or natural streams other than those producing the overflow. Examples of such lands are many tidal marshes and the vast areas in Arkansas, Mississippi, and northern Louisiana, where the land, protected from the Mississippi River by great levees, has good gravity drainage outlets through other streams.

But most overflowed lands are not so fortunately located. Ordinarily, in addition to a protective levee system a pumping plant is required for lifting the interior drainage water out over the levee. In fact, numerous cases may be found in which, when the levee system was first constructed, reliance was placed solely upon gravity outlets for disposing of the interior drainage water, but subsequent experience showed that by this means alone satisfactory reclamation of the land could not be secured; hence, a supplementary pumping plant, not contemplated in the original plans, was later installed.

The two characteristics which any agricultural drainage project must possess for its perfect success are, first, effectiveness, and, second, profitableness. If an elaborate plan for drainage improvement, when actually carried out, fails to drain the land sufficiently to secure a satisfactory cultivable condition the project is a failure. In fact, it is even worse than a failure, for not only may it mean an actual financial loss to its owners, but as an example may discourage others from undertaking other meritorious projects. So vital is it to secure adequate drainage, if any work at all is undertaken, it would seem that everyone connected with such work would appreciate its importance. Yet almost innumerable instances can be found where drainage improvements have been planned and constructed on a scale entirely too small to secure efficient results, and where those responsible for carrying out the work should have known in advance that the benefits resulting from their misdirected efforts would not be commensurate with the expenditures incurred.

It is characteristic of almost all artificial drainage improvement that, if a certain amount of work is needed, the actual construction of a part only of the whole work will not produce a correspondingly proportionate benefit. That is, if only one-half of the needed work is carried out much less than one-half of the full benefit will be obtained. It is, perhaps, approximately true that the carrying out of three-fourths of the needed work would yield one-fourth of the total benefit. The last one-fourth of the work produces perhaps three-fourths of the benefit. It is on account of this relation that the original planning of all drainage work on a sufficiently comprehensive and adequate scale is so important.

Naturally those who have had no experience in constructing drainage improvements can have little comprehension of the innumerable difficulties and obstacles that may arise in the construction of extensive work and in its operation after completion; and, too often, when they have the responsible charge of such work, they are prone to refuse to accept the advice of others who have had extended experience. There are still intricate problems and baffling uncertainties, numerous enough, in securing drainage in difficult situations, but there would seem to be no excuse nowadays for undertaking important work in violation of fundamental principles of drainage science well known to every experienced worker in this field of engineering.

It is not alone sufficient, however, that the drainage work as constructed shall secure the desired benefit. The work must be done economically and in such a way as to secure the greatest profit to the landowner. Several quite different plans for the drainage of a given district might secure equally well the desired improvement. In such a case that plan should be chosen which will prove cheapest in the long run, and to determine the best and cheapest plan is the special province of the engineer. The engineer has been defined as a person who can do with one dollar what anyone else can with two. One of the first steps taken in beginning a large drainage project should be to secure the services of a competent and experienced engineer. Such a man is needed to make the necessary surveys and plans for the work; to make inspections and estimates during construction; and, when a pumping plant is a part of the work, to test the completed plant to see that it complies with the specifications and meets the guaranties of capacity and efficiency. He is needed also to advise as to the most economical and efficient operation of the plant after its completion and as to its management, maintenance, and care.

Drainage by means of pumps has been carried on in European countries for the last 100 years and has been rapidly increasing in this country during the last 25 years. Through this extensive experience, including numerous failures, a considerable amount of knowledge is now available on the subject of the proper arrangement and the requisite capacity of pumping plants. It is the object of this bulletin to discuss the various questions arising in connection with the reclamation of agricultural land by means of pumps in order that the conclusions drawn from experience may be available to all landowners, district officers, and drainage engineers who are interested in this kind of drainage.

DRAINAGE PUMPING IN NORTHERN EUROPE.

Draining with the aid of pumps or what may be termed "lift drainage" is required for large areas of productive agricultural land in Europe. Notable examples of successful work of this character are found in Holland, eastern England, and in Ireland, while large marsh areas in both northern and southern Italy depend upon pumps for adequate drainage. The development of mechanical means of removing water from the land has in most instances been forced upon landowners when gravity drainage failed to give sufficient relief, and for that reason the movement was slow, particularly in the early history of such drainage. The pumps which were first used were the well-known scoop wheel and the Archimedean screws, which were driven by windmills.

The Zuidplas polder of Holland, containing 10,363 acres, lies 22 feet below the level of the River Yssel, into which it is drained. In 1825 the basin was drained by dividing it by a canal into two parts and raising the water into the river by two lifts, the first or lower lift being accomplished by 15 windmills driving 8 Archimedean screws and 7 scoop wheels. For the upper lift there were 15 windmills driving 10 screws and 5 wheels. These were later supplanted by two pairs of pumping stations, each having scoop wheels and centrifugal pumps, all driven by steam, by which means the drainage of the entire tract is now accomplished.

The great Haarlem Lake of Holland is often referred to as the most remarkable pumping drainage project known. The total area of the tract, which is now surrounded by a canal 37 miles long, is 41,648 acres, 3,011 of which are occupied by roads and main waterways. The water in this lake, which originally was 15 feet deep, was removed by pumps in 1852, 39 months having been occupied in removing the water. It is kept drained by three immense pumping plants of 350 horsepower each, located at opposite sides and at one end of the great basin. The combined capacity of the three plants is nearly 2,000 tons of water per minute raised to a height of approximately 15 feet. The area which was formerly a lake is now traversed by well-improved highways and is occupied by about 20,000 people.

The drainage of large portions of the fenlands in eastern England was originally accomplished by means of scoop wheels operated by windmills. It was not an uncommon occurrence for the districts to be inundated, because of the failure of the pumps to operate when required to remove the water. Losses from this cause became so great that the several plants were gradually equipped with steam power, which rendered the drainage of the land much more certain than under the old system.

Mr. W. H. Wheeler, in his " History of the Fens of South Lincolnshire," states that the entire fens known by that name cover about 363,000 acres, of which about 85,000 acres are from 6 to 12 feet below high-water level, and that 124,600 acres of this area are drained by steam power. The pump originally used was the large scoop wheel which is still operated in many of the plants, but the centrifugal pump is gradually being introduced as being better suited to the conditions which now prevail. The same author in his book entitled " The Drainage of Fens and Low Lands," enumerates 13 distinct districts having areas varying from 800 acres to 35,000 acres which are now drained by steam plants which operate either the improved scoop wheel or the more modern centrifugal pump.

From available data it appears that not less than 203,000 acres of lowland in eastern England depend upon pumps for their drainage. The efficiency of these plants has from time to time been greatly increased until it is now estimated that the average cost of pumping in eastern England is 2 cents per acre for each foot the water is raised.

The conditions which are found in Europe are in many respects different from those we are required to meet in this country. The history of drainage by pumping, however, during the last 100 years shows a gratifying and substantial development of mechanical devices and the utilization of power for draining, and establishes beyond question the practicability of this kind of reclamation. The experience and practice of northern Europe are exceedingly valuable to those who contemplate the design and construction of works of this class, a study of which should prevent us from falling into certain errors which have at times been expensive and discouraging to European enterprise in land development.

PAST EXPERIENCE IN THE UNITED STATES.

In this country, among the plantations in the lowlands along the Gulf of Mexico, pumping has been in vogue for a long time, especially for the drainage of lands devoted to the cultivation of sugar cane. More recently pumping has been extensively introduced in the bottom lands lying along the Illinois River and the adjacent portions of the Mississippi. Along the Illinois, though pumping was first tried about 20 years ago, little had been accomplished previous to 1900. Since 1905, however, numerous large plants have been constructed, and in the spring of 1910 ten separate plants were in operation pumping the drainage water from a total area of about 85,000 acres. These plants have a combined capacity of about 2,000 horsepower and represent an investment for machinery alone of some $150,000. There are under construction three additional plants to provide for about 33,000 acres more of land.

Along the Mississippi River, between Muscatine, Iowa, and Hannibal, Mo., there are in operation or nearing completion six large pumping plants planned to be able to pump the drainage water from 150,000 acres. In Illinois, along the Illinois River, the greater part of the bottom land has already been thus reclaimed. In other States the movement is just beginning, and it is now evident, from the numerous inquiries for information, that there exists at the present time a very active and widespread interest in this whole question.

The experience of those who undertake projects for pumping drainage water, without previous experience in similar work or full and accurate knowledge of what has been accomplished elsewhere, shows that invariably they greatly underestimate the magnitude and difficulties of the work contemplated. In this regard their experience is identical with that of those who have been pioneers in other forms of agricultural drainage work. As a consequence the first pumping plants were entirely inadequate in capacity, inefficient in operation, and largely a waste of the money invested in them. In numerous cases they have been added to or entirely replaced by the building of new plants. Some of the recent large plants, however, with their ample and economical machinery, are models of convenient arrangement, permanence, and durability.

In the upper Mississippi Valley the various conditions prevailing, such as intensity and distribution of rainfall, length of growing season, and kinds of crops raised, differ widely from those obtaining near the Gulf of Mexico in Louisiana, leading to correspondingly wide variations in recent drainage practice. The former situation will here be taken up in detail and the planning of districts, the requisite sizes and kinds of machinery, the first cost, and the cost of maintenance will be discussed. The situation in Louisiana is dealt with in a previous publication of the office.[1]

PUMPING IN THE UPPER MISSISSIPPI VALLEY.

In Illinois and the adjacent States, the bottom lands which have been reclaimed by pumping are in the heart of the corn belt and possess a heavy, rich black soil, mixed in places with a varying amount of sand. They are adjacent to thickly populated lands, the best of which is worth $150 per acre, and in some cases lies within a few

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[1] U. S. Dept. Agr., Office Expt. Stas. Doc. 1315.

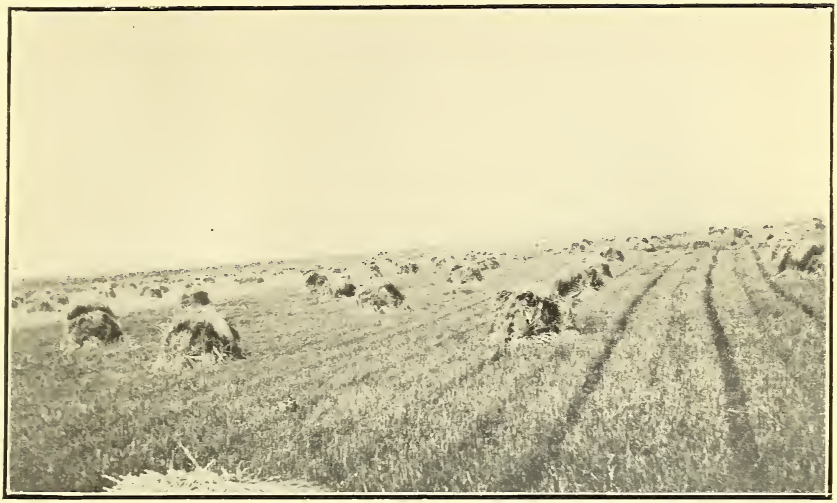

FIG. 1.—CROP OF 1910, COAL CREEK DRAINAGE AND LEVEE DISTRICT.

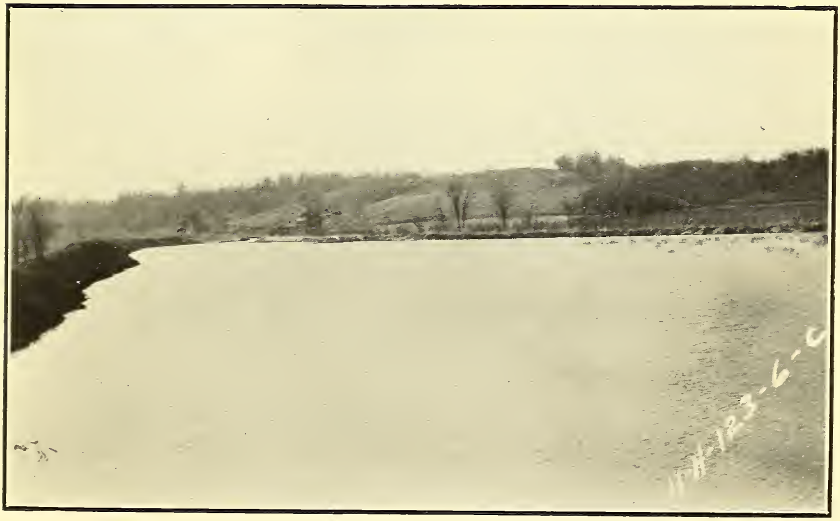

FIG. 2.—HOOD BASIN, COAL CREEK DRAINAGE AND LEVEE DISTRICT.

miles of large towns. This proximity to some of the most fertile and highest-priced agricultural lands in the United States has led to an earlier activity in drainage reclamation than has existed in most other portions of our country. The results of adequate protection and drainage are shown by figure 1 of Plate I, a view of part of a tract of reclaimed land on the Illinois River.

SIZE OF PUMPING DISTRICTS.

In order that the building of a levee around a tract of overflowed land and the installation and operation of a pumping plant may be carried out economically at a moderate cost per acre of land reclaimed, it is necessary to have a considerable area included in a single project. Hence, ordinarily, the land does not belong to a single owner, but rather to a number of individuals. In order that all the interested landowners may work harmoniously together it is necessary, first, that an incorporated drainage district be formed according to the method provided by the specific laws of the particular State relating to this subject. The officers of the district so formed may then proceed to carry out the necessary successive steps in the inauguration of the construction work.

Pumping districts of as small an area as 3,000 acres may profitably be formed in favorable locations; but, in general, the expense per acre is less, as the district is larger, up to a certain limit beyond which there is no further advantage from increased size. According to experience, about 10,000 acres of reclaimed land seems to be a very satisfactory size for such a district.

The boundaries of a district are determined by the natural surface conditions. A district will naturally include all the land on one side of the river between the channel and the bluff and extending up and down the valley from one tributary to the next of any size entering the river on the same side. Hence, a district may be but 1 or 2 miles wide, the part width of the river valley, but will ordinarily be much longer up and down the valley.

LEVEES.

The protective levee begins at the bluff at one end of the district, follows along the bank of the entering tributary to its junction with the river, thence along the river bank to the other tributary, and up that again to the bluff. Thus, ordinarily, the levee extends continuously around three sides of the district. The correct location of the levee to secure a good foundation and to leave sufficient floodway for the river, and its proper construction of sufficient strength to resist erosion, undermining, and overtopping, are engineering questions of vital importance to the welfare of the district. It was the unfortunate experience of nearly every one of the early levee districts on the Illinois River that, as first constructed, the levees were entirely inadequate in size and strength, with the result that they were broken by floods, their interiors were inundated, and years elapsed before the districts recovered from the injury.

The height of the levees varies all the way from zero, at their ends against the high ground, to 20 feet in places, but they are in general between 8 and 12 feet high. The dimensions which a levee must have in order that it may be strong enough and be durable depend upon the kind of material used in its construction, the method of construction, and the nature of its exposure to the action of waves and currents. A tenacious clayey soil or gumbo will in general make the best levee. Experience shows that the least dimensions which a finished and compacted levee should have are a width on top of 6 feet, a slope on the river side of 3 horizontal to 1 vertical, and a slope on the land side of 2 to 1.[1] Where the location is such that the water remains against the outer side of the levee for only short periods of time, and where the material is good, the total slope of 5 to 1 might be divided equally between the two sides. If the material used is very sandy, or if the bank is to run any risk of being exposed to a strong current or any wave action, flatter slopes must be used. On account of the difficulty of maintaining a levee in good condition, a topic discussed more fully later in this bulletin, it is in many locations absolutely essential, and is always desirable, not to have the slope on either side of the levee steeper than 3 to 1. The crown of the levee should be at least 3 feet above the highest expected high water.

Levees are built with dipper dredges, with drag-bucket machines, and with scrapers. If the material is put up wet there will be very little subsequent settlement, but if scrapers are used the original height of the levee must be increased by at least 10 per cent to allow for the settling during the first year or more. In any case, the material used to form the levee must all be taken from the river side of the embankment and a clean berm, at least 10 feet wide, must be left between the toe of the slope and the nearest point of the borrow pit. The latter must be kept shallow on the side near the levee, with a slope not steeper than the levee slope, so as not to undermine the embankment, and in no case must the excavation cross the imaginary line formed by extending the line of the outer slope of the levee down below the surface of the ground.

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[1] This statement applies particularly to the larger rivers, such as the Illinois, where the flood waters frequently remain against the levees for some length of time. On creeks and smaller streams, where the water will only stand against the levee for short periods of time and where the material is good, steeper slopes may often be used and top widths even as small as 3 feet are sometimes admissible.

Before constructing the levee the entire area to be occupied by it should be cleared of all vegetation and all stumps and roots should be grubbed to a depth of 3 feet. The entire surface should then be plowed with a large dead furrow in the center. This treatment for the foundation may suffice if the material is firm and dense, the levee only moderately high, and the water not constantly against the levee. But where any unusual dangers exist there should be dug under the center of the levee a continuous muck ditch 2 to 4 feet wide and 3 or 4 feet deep, or deeper if needed, to cut off any possible seepage through the surface soil. The muck ditch should be filled with the best material obtainable, preferably a clayey mixture, well compacted. No vegetable matter should be permitted in any of the material used to form the levee. Insufficient care in preparing the foundation for levees has been the most frequent cause of subsequent disasters.

The care of levees subsequent to their completion is an important matter too often neglected. The slopes should be smoothed and as soon as practicable a good growth of grass should be secured. For this purpose bluegrass, Bermuda grass, redtop, timothy, and clover are all used. A good growth of sod will hold the soil in place and prevent erosion. A mowing machine can be used on a 3 to 1 slope, but scarcely on a steeper slope. On a steeper slope, too, beating rains are likely slowly to wash out the soil and thus gradually reduce the height of the cross section. All weeds and brush on a levee should be cut at least twice during the growing season, as they are particularly harmful, loosening and disintegrating the soil by their roots. Sometimes the top of a levee is used as a road, but this practice is not to be commended, for the wagon wheels cut off the corner of the top and the ruts likely to be formed grow rapidly to such dimensions as seriously to affect the height and efficiency of the levee. The proper place for a road along a levee is on the level ground just inside its inner toe. Burrowing animals of numerous sorts are a constant menace to the integrity of a levee, and they should be assiduously hunted and driven away. Frequently levees are pastured. This has the advantage of keeping down the vegetation, keeping the soil compacted, and driving away burrowing animals. The slight damage to a levee which may result from using it as a pasture is easily observed and repaired and is probably counterbalanced by the good results of the practice.

Constant attention and expense, the latter not large, are required for the proper maintenance of a levee. In the long run it will be found infinitely more profitable to incur this small regular expense rather than to invite disaster during some period of unusually high water by permitting the levee to deteriorate to the danger point. Proper maintenance will be found the best economy in the end.

The strip of land occupied by the levee should not be located too close to the natural banks of the stream whose waters are to be diked off. Consideration must be given to the question of leaving outside the levee a sufficiently wide flood channel. The conclusion reached in any particular case will depend upon the conditions existing upon the opposite banks of the stream, and no definite rules can be stated. If the banks of the stream are subject to cutting or caving, the question of the future permanence of the levee enters. A strip of timber should be left outside the borrow pit to form a protection for the levee during high water against erosion by too strong a current, and against destructive wave action during high winds. Where practicable, bars across the borrow pit should be left at intervals so as to prevent too strong a current near the levee. No sharp corners should be made in the line of the levee's location.

For a more complete discussion of levee construction, methods of protecting inadequate work in emergencies, and the repair of levees after they have been overtopped and broken, the reader should consult a previous publication of the office.[1]

INTERIOR DRAINAGE DITCHES.

An excessive and injurious amount of drainage water may accumulate within the district from three sources: (1) Rainfall; (2) run-off from higher lands draining naturally into the district; and (3) seepage under the levees when the river level is higher than the surface of the land inside the levee. This water must be collected in ditches and led to some suitable point near the levee where the pumps may lift it over the levee and discharge it into the river. The amount of rainfall to be removed by pumping depends upon the amount and distribution of the seasonal precipitation.

The run-off from the bluff lands will depend upon the topography of the adjacent higher lands and the natural watershed boundaries, and the task of disposing of it is often one of the most serious problems to be solved in the planning of a district. The amount of water thus entering the district should be reduced as much as possible by proper location of the levee and by a diversion ditch wherever the latter is feasible. The only district known of where this has been tried on an extensive scale in this country until the last year is Coal Creek drainage and levee district near Beardstown, Ill., a map of which is given as figure 1. A large diversion ditch and levee has been constructed along the base of the bluff for a distance of about

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[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 158, Separate 9.

4 miles, from the point where Coal Creek debouches from the hills, to the lower end of the district. The levee is on the lower side of the ditch; that is, toward the district. Not only is the flow of Coal Creek received by this diversion ditch, but several smaller streams also flow into it. The first diversion ditch, made several years ago, although sufficiently large at first, became too small by being filled with sediment brought down from the hills during floods, so that the various streams overtopped the levee and flowed into the district. In 1909 another ditch and levee were completed, but these differ from the

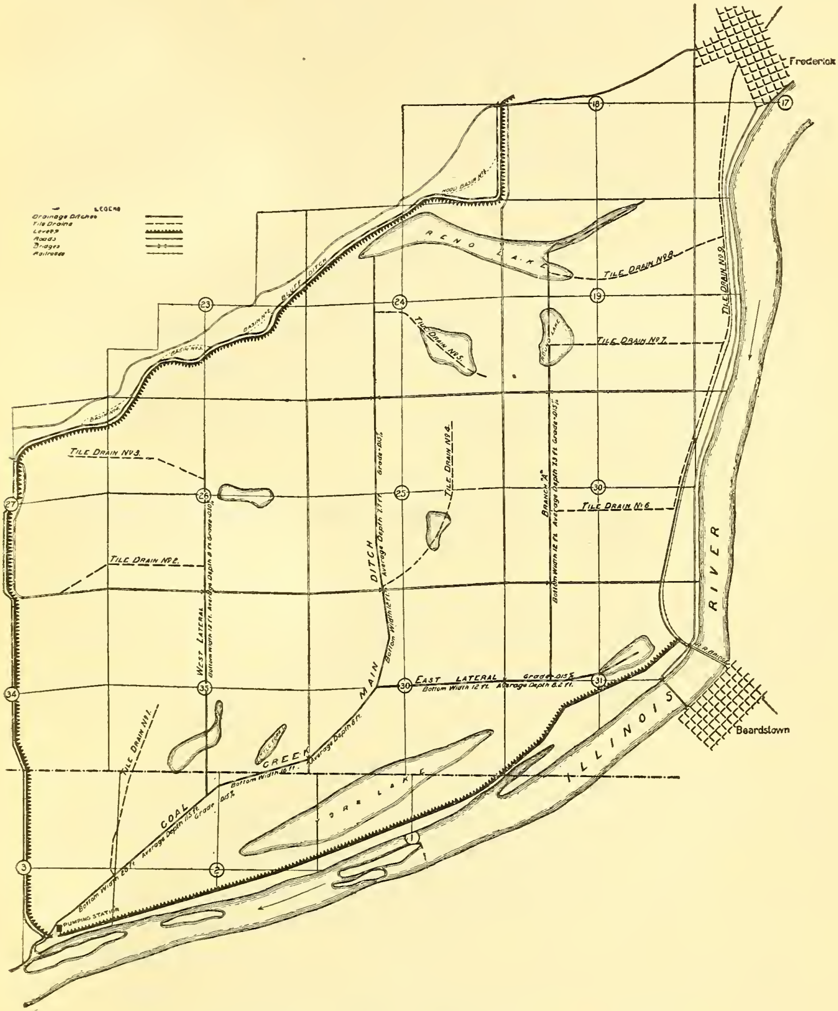

FIG. 1.—Map of Coal Creek drainage and levee district, Illinois.

previous construction by being so located as to include a settling reservoir opposite the mouth of each stream. It is expected that these reservoirs will receive the sand and sediment brought down from the hills and thus prevent the ditch from becoming clogged. The reservoirs are planned to be of sufficient size so that they will not become filled with sediment for many years. Two of them are 5 and 20 acres in extent, respectively, while two are of 6 acres each and three are of 4 acres each. Figure 2 of Plate I is a view looking west-northwest across Hood Basin, the largest of the reservoirs. Across the basin may be seen a part of the embankment of the original diversion ditch which failed. The hills in the background show the nature of the country drained by Coal Creek. Two years' experience with the last ditch indicates that it will prove quite satisfactory, though it is to be remarked that the seasons of 1909 and 1910 were not wet enough to afford a crucial test of the system. Recently the Crane Creek drainage and levee district has constructed a somewhat similar diversion ditch. In England and Holland diversion ditches to prevent drainage water from flowing from higher lands onto lower areas, to the damage of the latter, have been in systematic use for a long time.

If the levees are properly constructed, as heretofore explained, the amount of seepage water passing under them is ordinarily so small as to be negligible, but if the soil or the subsoil of the district be very sandy, or if the levees have been carelessly constructed upon an improper foundation, the seepage may accumulate in sufficient quantity to be troublesome. Ordinarily, if land near the levee is injured by seepage, the difficulty may be corrected by laying a line of tile parallel to the levee and 50 to 100 feet from the toe of the slope.

The determination of the proper size and arrangement of the interior drainage ditches for a pumping district is not fundamentally different from the planning of a gravity ditch system for an ordinary district. The same hydraulic principles apply to the one as to the other, but in some details essential modifications are necessary. Ordinarily river-bottom land has a somewhat uneven surface, varying in elevation by several feet, and lies in long ridges and depressions, the latter bearing local names as lakes, sloughs, or creeks. The ridges may be quite sandy while the lakes contain a heavy black soil. To fit all the land for cultivation the drainage system should be planned to keep the ordinary ground-water level at least 3 feet below the surface of the ground in the lowest spots that are to be cultivated. This is necessary, not only for the purpose of providing room for the root systems of growing crops, but also as a margin of safety by furnishing a reservoir capacity in the drained soil for the temporary storage of water after an unusually heavy period of rain.

In some localities there are sloughs so low that to drain them would require undue expense. In such a case it is better to reserve these areas for use as reservoirs in connection with the ditch system, with the expectation that they will fill with water during heavy rains and store it until it is gradually removed by the operation of the pumps. This tends to reduce the maximum capacity required of the pumping plant of the district concerned. Some districts on the Mississippi River have as much as 7 per cent of their total area occupied by such storage basins, but other districts have none at all, and such storage areas do not seem to be essential in regions where the natural condition of the ground surface is not favorable for their use.

The main ditch and its branches should traverse the lowest areas in the district, following the land subdivisional lines where practicable. This will secure surface drainage in the lowest areas, where it is most needed, and also prove cheapest because the amount of excavation will be a minimum. Cutting ditches through the ridges should be avoided as much as possible, especially where these are sandy, on account of the great difficulty of making and maintaining a ditch in sandy soil owing to the trouble caused by the caving banks. At times the previously existing natural drainage channels, when suitably cleaned, may be made to form a considerable part of the ditch system.

Often the district, as a whole, may have very little surface slope and it becomes necessary to dig the main ditch with a bottom without grade. To compute its carrying capacity, then, it must be assumed that the pumping plant when in operation at full capacity will lower the water level at the pump by amount equal possibly to 3 feet or more. A comparison of this level with the permissible water-surface level at the upper end of the ditch will give a surface slope for computing the velocity in the ditch. This surface slope will not often need to be less than 3 inches to the mile. From the velocity of the water as computed and the available cross section of the ditch at the lowered water level the carrying capacity of the ditch is determined.

The greatest amount of sediment is likely to be washed into the main ditches during a heavy storm when the ditches are bank full. It should be noticed that at such a time there is an important difference between the condition of these ditches and that existing in main ditches of gravity-drainage systems. In the latter, when more than normally full, the velocity is a maximum and hence there is the least possible tendency toward the deposition of sediment in the ditches.

But in a pumping district, on the contrary, when the main ditches are unusually full, the velocity will be low and hence sediment may be easily deposited. In general, the velocity in these ditches will always be so low that they are not self-cleaning. On this account, as well as on account of the drawing down of the level in the ditches by the pumps, such ditches should be of unusually generous dimensions. The engineer will wisely give particular attention to the designing of the ditches to insure ample depth and breadth to provide the requisite capacity. In general, it is probable that the main ditches should be dug from 8 to 10 feet deep. Figure 1 of Plate II is a view of the main ditch, Coal Creek drainage and levee district, Illinois, which was constructed in 1909 with a dipper dredge having side spuds. The view was taken before the ditch was completed at the lower end. The water level as shown is about 4 feet below the ground surface and about 4 feet above the normal level after the ditch was completed. Figure 2 of Plate II is a view looking up Branch A of east lateral, from near the outlet of tile drain No. 7.

Experience shows that to put bottom land into perfect agricultural condition some tile drainage is usually necessary. Where this has once been demonstrated the landowner, who has already been put to considerable expense for the main drainage of the district, is not content to have his land in anything but the most fertile condition and hence is usually quite willing to go to the comparatively small additional expense involved in the necessary tiling. Parallel lines of 5-inch or 6-inch tile are laid at such distances apart as the elevation, slope, and nature of the soil require. Where the lines are long, larger sizes are used in the lower portions. The distances between parallel lines found necessary by trial is usually between 10 and 30 rods, and their minimum depth below the surface should not be less than 30 inches.

On account of the surface erosion and consequent sedimentation in the main ditches, small open-surface field ditches or laterals emptying into the main ditches are highly objectionable unless for some distance back from the junction they are dug as deep as the bottom of the main ditch. The difficulty could be avoided by the use of some sort of permanent and stable masonry inlet; otherwise, small ditches should be replaced by tile.

GRAVITY SLUICEWAYS.

In the case of districts where the river falls low enough during the latter part of the summer to afford an outlet for gravity drainage, sluiceways, so arranged that they may be opened when desired, should be built under the levee near the pumping plant. The sluices

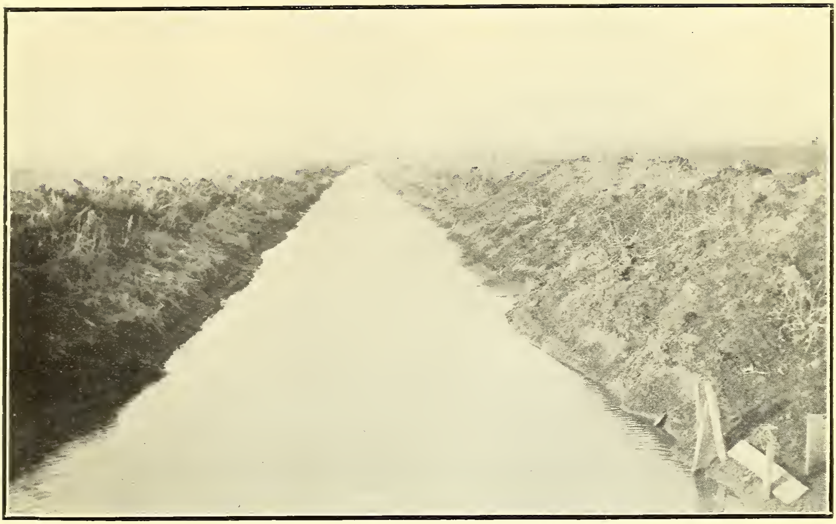

FIG. 1.—MAIN DITCH, COAL CREEK DRAINAGE AND LEVEE DISTRICT.

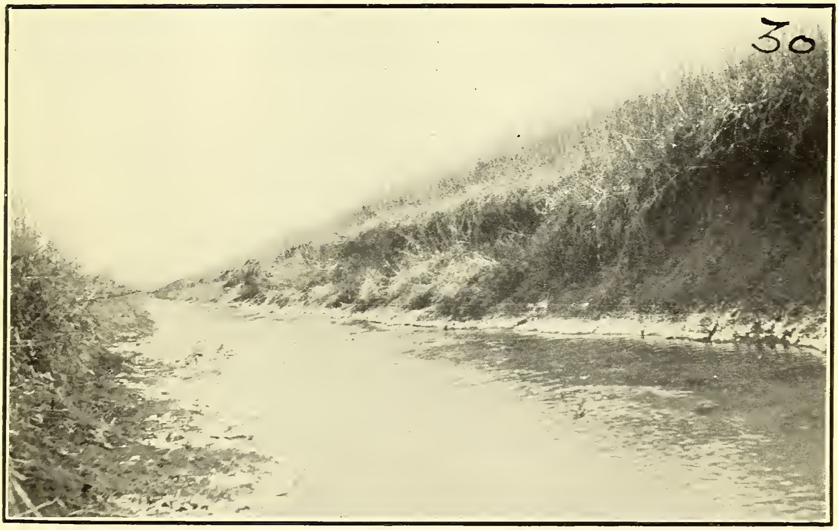

FIG. 2.—BRANCH A, COAL CREEK DRAINAGE AND LEVEE DISTRICT.

should be composed of one or more parallel pipes laid nearly level and provided with suitable valves. The length of the pipes will naturally be 100 feet or more. Metal, concrete, or vitrified sewer pipe may be used in their construction. Both ends should be protected with strong concrete bulkheads, and cut-off walls should be placed around the pipes at intervals along their length to prevent seepage along their exterior surface. Cracking and failure of these end bulkheads, one of the commonest accidents in drainage districts, show that they must be made with special care, amply deep, and of liberal dimensions. If the outer end of the sluiceway is not below low-water line of the river, the bottom of the channel, through which the water will flow beyond the end of the pipe, should be protected from washing out by riprap, paving, or a concrete floor carried to a safe distance. Where feasible, this protection should extend below low-water line.

The sluiceway should be sufficient in size to discharge in 24 hours such an amount of water as would cover the whole drainage area one-fourth inch deep. In making this calculation the velocity of the water through the sluiceway should not be assumed to be greater than 5 feet per second. The sluiceway openings should be low enough so that their highest point will be at about the line at which it is desired to maintain the water level within the district. Their interior surfaces should be as smooth as possible in order to reduce the friction which retards the flowing water. If the entrance to the pipes is made well rounded, their maximum discharging capacity will be considerably increased. Automatic outward-opening flap valves may be put on the outer end of the pipes, but in important cases there should be also a place where the pipe may be closed by stop planks or by a gate valve if the automatic valve should get out of order.[1]

NECESSARY CAPACITY OF PUMPING MACHINERY.

Before discussing in detail the conditions determining the size needed for a pumping plant it will be illuminating to describe the general method of operation of such a plant in the latitude of Illinois. In the late summer and fall, since the precipitation is slight and is more than balanced by evaporation, the pumps are not run. During the winter storms are more frequent and evaporation is small, so that gradually the ground becomes completely saturated and the ditches full. Some districts pump occasionally throughout the whole winter; others start the pumps at some date in the spring and operate them continuously night and day for several days to remove the large accumulation of water stored up during the winter months. Gradually the water level in the ditches is lowered, and when the desired minimum is reached the machinery is stopped during the night. The water will rise in the ditches perhaps 2 or 3 feet during the night. When the pumps start up in the morning the water level at the pumping plant quickly drops a foot or more and then less slowly for the rest of the day. At points some distance away the effect of starting the pump is less quickly seen in the morning, but the lowering of the water is gradual throughout the day. After a few days of such operation the supply of water diminishes and the pumps are not run the whole day.

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[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 158, Separate 9.

Later, since it is troublesome to start up a big plant for only a few hours of operation, the speed of the engine and pump is reduced to diminish its discharge, or, if there is more than one pump in the plant, only one may be run. At last, days are skipped and pumping ceases entirely. After every rain of any importance, the pumps are started and a similar cycle of operations transpires, extending over a longer or shorter period, according to the amount of water to be removed. In some districts pumping for the season ends in June, and drainage is by gravity for the remainder of the summer. In others no gravity drainage is available, and the pumps must be run later in the season. Thus it is clear that, though the pumps must constantly be in readiness for use, their operation is very intermittent. The total time of running in a whole year never exceeds 60 to 90 days of 24 hours each. In some seasons it is not more than 15 to 20 such days.

The size of pumping plant required for any particular district depends upon a variety of conditions, among which are the size and slope of the drainage district and of any other area from which drainage water is received; the amount of storage capacity available in ditches and reservoirs; the system of interior drains used and the method of construction adopted for the levee; the nature of the soil and subsoil; the method of operation of the pumping plant; the kind of crops raised and the degree of drainage required; and the amount and distribution of the rainfall throughout the year.

In the vicinity of Illinois the weight to be given to some of these factors is very small, and in the present state of our knowledge no definite allowance can be made for them. Yet, notwithstanding our ignorance concerning some of them, it may be profitable to discuss briefly the nature of the effect of each. This is a field in which much careful study is still needed and must be carried out to secure the complete knowledge necessary for the most satisfactory design and management of the pumping machinery of drainage districts.

Along the Illinois and upper Mississippi Rivers the majority of pumping plants already installed have been planned to have a maximum pumping capacity sufficient to remove in 24 hours one-fourth inch in depth of water over the entire district. This is equivalent to 6.74 cubic feet per second per square mile of drainage area, or 0.0105 cubic feet per second per acre.

It is doubtful whether any change should be made in the one-quarter inch coefficient solely on account of change in the size of the district; however, where some portions of the district are materially higher than others, the coefficient might be increased to prevent danger to the lower portions from the run-off from the higher areas. Where drainage from higher land flows into the district a larger run-off coefficient must be used for the higher area. The proper amount depends upon the nature of the country. For rolling pasture land free from undergrowth, or for cultivated corn land, probably an increase of 50 per cent in the coefficient, or a total of three-eighths inch, for such upland areas is none too great. Where feasible, the drainage from such higher areas should be diverted around the district instead of being brought to the pumping plant, as previously explained on page 18.

With a considerable reservoir storage area within the district, the size of the pumping plant may be materially reduced. If the storage area equals 5 per cent of the total area, a 2-inch rainfall, all running into the reservoir, would raise its level only 40 inches. Therefore, if a rise of 3 feet in the reservoir can be permitted it would seem that the capacity of the pumping plant could certainly be reduced by one-third and possibly to one-half of what would otherwise be required.

If tile drainage at a depth of 3 feet or more is extensively used, the demand upon the pumping plant will be somewhat reduced, for the tiled land will act like a reservoir in storing a large amount of water and will deliver it only slowly to the ditches. On the other hand, an extensive system of shallow open field ditches will deliver the rainfall rapidly and may thus damage any especially low areas unless the capacity of the pumping plant is increased. If the levees have been properly constructed, as previously described, the amount of seepage through them can never be sufficient to affect the pumping plant. Cases have been known, however, of levees so poorly built that the quantity of water coming through them was sufficient not only to endanger the stability and safety of the levees themselves, but also to increase appreciably the amount of water to be pumped.

If the soil is very stiff and tenacious the surface run-off after a heavy summer shower will be greater than from a porous open soil. During a time of flood in the river, a sandy subsoil may develop springs and boils, not only in the bottoms of the ditches, but sometimes even in the fields. The quantity of water that may be received in this way is very uncertain but it is not probable that it is often sufficient in amount to affect the pumping plant.

A pumping plant that is designed to operate night and day may, of course, be smaller than one intended to operate only in the daytime. Practically all plants are expected to run nights occasionally, when needed. Pumping plants are operated chiefly during the months from March to June. One of the times of longest continuous operation during the whole year is always at the beginning of pumping in the spring, because if there has been no pumping during the fall and winter the rains and snows will have completely saturated the ground and filled the ditches. Hence, those districts which have had the longest experience in pumping are unanimously of the opinion that even though at that time there is no danger of immediate damage to crops, still it is best to pump occasionally during the winter so as to maintain the ground water constantly at a low level, and thus secure the great advantage of early drying of the soil in the spring and the opportunity for early cultivation and planting. Moreover, the lower the normal ground-water level is kept below the surface, the less will be the flooding effect of a severe storm.

It should be clear from the foregoing discussion that a district which gives especial care and attention to its pumping, running throughout the winter as needed and frequently during the growing season, so as to maintain a minimum ground-water level while there is any danger from the occurrence of heavy and sudden rains, will require a smaller pumping plant than would otherwise be needed.

From a surface covered with a growing hay or grain crop the run-off is less rapid than from land in corn. For corn and hay the ground water must be kept at a lower level than is necessary for grain. Corn is considered the most profitable crop in the region under consideration, and where the soil can be kept sufficiently dry it is raised as frequently as is consistent with a proper crop rotation necessary for maintaining the fertility of the soil. Much land can be observed, however, which is not sufficiently drained for the most successful raising of corn and which therefore is devoted to wheat and oats instead.

The amount and distribution of the rainfall are the chief factors determining the size of pumping plant required in a given location, and we shall proceed to a detailed discussion of all the evidence that it has been possible to gather bearing upon this point. From a consideration of all the data, the conclusion seems justified that in the present state of our knowledge the run-off coefficient of one-fourth inch in depth over the whole drainage district in 24 hours is the correct one to use in designing pumping plants on the Illinois and upper Mississippi Rivers. Direct observations on numerous plants in actual operation for a series of years will be needed to settle the question finally.

In the region referred to, though some pumping on an inadequate scale has been carried on for more than 10 years, all the older plants until recently had troubles with their ditches and levees which prevented their pumping experience from furnishing conclusive data, and from no plant has it been possible to obtain definite records going back more than two years. Now, though there are nearly a dozen large plants in operating condition, it is still surprising to learn that some of these neglect to keep even the simplest, most fundamental records, such as would determine whether the plant is operating economically or wastefully—records which would be of great use to others as well as to the district immediately concerned.

As indirect evidence it may be stated that for many years in central Illinois the one-fourth inch coefficient has been used in designing ditches for the drainage by gravity of flat lands and has been found adequate and satisfactory. For a much longer time in Holland and in the fens of England the coefficient of one-fourth inch or a little more has been the basis used in the designing of pumping plants. Although their total annual rainfall is about the same as in Illinois, their climate is otherwise quite different. In England and Holland there are many more rainy days, so that the rainfall is much more evenly distributed than in this country. In these countries, too, there is much less sunshine and hot weather in summer and therefore less rapid evaporation. On the other hand, they do not have such violent and excessive rains falling during brief periods as we have.

From two districts on the Illinois River valuable data were obtained. During the history of its pumping, extending over nearly 20 years, the Pekin-La Marsh levee and drainage district, near Pekin, has used in succession four different sources of power, including two sizes of steam engine, a producer gas plant, and electricity. It has also used at least four different sizes of centrifugal pump. In March, 1908, the producer gas pumping plant was tested by men connected with the faculty of the University of Illinois and the 26-inch centrifugal pump was found to be discharging 28.7 cubic feet per second. Although the nominal rated capacity of the pump is about 37 cubic feet per second, from all that can be learned it seems probable that the average discharge of the pump, when run by the producer gas engine, could not have exceeded 30 cubic feet per second. Since the drainage area of the district is about 3,000 acres, this is equivalent to 1 cubic foot per second for 100 acres of land, or a capacity sufficient to remove 0.24-inch depth in 24 hours. In 1909 this plant started March 10 and operated intermittently, as required, until

July 25, during which time it kept the district satisfactorily dry. A rough daily memorandum kept by the engineer in charge shows a total operation during this period of 1,098 hours, equivalent to 45.7 24-hour days. The total depth of water removed was 45.7 times 0.24, equal to 11 inches.

During this period the most severe test of the capacity of the plant was 4 days' steady operation, July 7–10, followed by 7 hours on July 11, or a continuous run of 103 hours. This was necessitated by a heavy rain on July 5, 6, and 7, the representative character of which will be discussed later. In October the district began pumping by electricity, and, to June 20, 1910, had run a total of 1,365 hours, equivalent to 56.9 days. It is quite certain that, as operated by the present electric motor, the pump has a higher speed and a greater discharge than when operated by the producer gas engine. But in default of precise information, if we assume the same discharge as before, the total water removed between October 15, 1909, and June 20, 1910, was equivalent to 13.6 inches in depth over the whole district. During all this period the electric pump was never run more than, and very seldom as much as, 12 hours in one day. As will be shown later, the year 1909, although not an extreme one, was rather wetter than the average, while 1910 has been remarkably dry. The Pekin-La Marsh district is generally considered to be the best and most completely drained district on the Illinois River, and is in an entirely satisfactory condition so far as drainage is concerned.

The Coal Creek levee and drainage district, near Beardstown, Ill., has been practicing pumping for a number of years, though not with entire success previous to 1909. The equipment includes one 24-inch centrifugal pump with a nominal rated capacity of 33.5 cubic feet per second and two 15-inch pumps rated at 15.5 cubic feet per second each, or a total capacity of 64.5 cubic feet per second. The area of the district is 6,700 acres, hence the nominal capacity of the pumping plant equals $\frac{64.5}{6700 \times 0.042} = 0.23$ inch in depth in 24 hours. The three pumps are run by one Corliss condensing engine which has been in operation about 10 years.

Since July, 1909, accurate and detailed daily records have been kept of the operation of this plant by its owners. Between July 1, 1909, and July 1, 1910, the only times when it was necessary to run all three pumps continuously night and day were once in July, 1909, and twice in May, 1910. The rainfall is measured at the pumping plant by means of a Weather Bureau pattern rain gauge. On July 7, 8, and 9, 1909, the total rainfall was 2.8 inches, causing all the pumps to be run continuously for 57 hours, after which one of the smaller pumps was stopped and the other two were operated during the third night. No more night running was required by this storm.

May, 1910, was a particularly wet month at this station, the total precipitation having been recorded as 6.8 inches, though there were no single remarkably heavy showers. On the first two days of the month 1.4 inches fell; on the 7th, 1.4 inches; on the 11th, 1.2 inches; from the 15th to the 17th, 0.8 inch. To meet this steady wet period all three pumps were run continuously for 72 hours from the 13th to the 15th and again for 42 hours on the 18th and 19th. The large pump was run every day during the month and during over two-thirds of the nights. At least one of the small pumps was run nearly every day and nearly as many nights as the large pump. The total operation of all three pumps, taking due account of the different sizes, was equivalent to operating all the pumps together for about 70 per cent of the time during the whole month. The elastic arrangement of the pumps in this station illustrates very well the advantage of having separate units in such a pumping station.

The pumps are frequently run at a decreased speed when the quantity of water to be lifted diminishes. Taking this into consideration, as well as the fact that as practically operated all such pumps when actually measured almost invariably show a capacity considerably below their nominal capacity, it seems probable that the pumps do not exceed 80 per cent of their theoretical discharge. With this conclusion the owners of the Coal Creek plant agree. Using, therefore, 12.5 cubic feet per second as the discharge of each of the smaller pumps and 25 cubic feet per second as the discharge of the large pump, the total amount of water removed from the district, according to the records kept at the plant, between July 1, 1909, and July 1, 1910, was equivalent to 24.3 inches in depth over the whole district, though in the first part of the season of 1909 some land was under water and much was too wet for satisfactory cultivation, this stored-up excess of water was removed and the whole district was maintained in proper condition. On account of the wet condition at the beginning of the season, the amount of water removed was greater than would have been necessary if the pumps had previously been operated satisfactorily. There are no data for determining how much the total depth removed (24 inches) would have been reduced by normal operating conditions. The greatest amount removed during any one month of the year was 3.7 inches in May, 1910, when the rainfall was 6.8 inches. The owners of the plant are convinced that its capacity is ample for the drainage of the district.

It remains to show how nearly representative were the rainfall conditions during 1909 and 1910, for which the pumping data obtained at the Pekin-La Marsh and Coal Creek pumping plants have been discussed above. A United States Weather Bureau station is located at Peoria, on the Illinois River. The following table gives for the last 10 years the annual rainfall for each month in which the precipitation exceeded 3 inches.

Annual and monthly rainfall, in inches, for all months exceeding 3 inches, at Peoria, Ill., from January 1, 1900, to July 1, 1910.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.[1]
1900		5.6			5.6								32.7
1901			4.3			4.3	3.1						26.0
1902					3.0	9.6	7.3	7.4	6.8	3.8			49.2
1903			3.7	5.2	4.2		4.9	7.2	5.8				39.8
1904			4.4	3.5	4.1			4.1	6.7				32.5
1905				4.0	4.5	5.1	4.2						32.4
1906						3.2			4.9				29.0
1907	5.4					4.0	4.9	6.6					34.9
1908		4.0		4.1	7.8	4.1	3.9						34.0
1909		3.7		7.2	3.7	3.6	4.6		3.7	3.6	5.5		42.1
1910				3.6	4.5								

[1] Average annual rainfall, 35.3 inches.

The greatest annual rainfall was 49 inches in 1902. The only other year in which 40 inches was exceeded was 1909. The only months in which the precipation exceeded 6 inches were: June, July, August, and September, 1902; August, 1903; September, 1904; August, 1907; May, 1908; and April, 1909. From this it is evident that a pumping plant to be satisfactory must be able to handle a monthly rainfall of 6 or 7 inches, and that this will be sufficient.

From the daily rainfall records a list was made of all the storms occurring at Peoria between January 1, 1902, and July 1, 1910, lasting one or more days, during which the total rainfall for the whole storm was 2 inches or more, but leaving out of the calculation all days on which the precipitation was less than one-fourth inch. There were 28 such storms, in 10 of which the total precipitation exceeded 3 inches, and in 4 of the latter the precipitation exceeded 4 inches. Hence a pumping plant should be able to handle a downfall in one storm of at least 4 inches. One of the above-mentioned four storms was long drawn out, covering six days in January, 1907. Probably much of the precipitation was in the form of snow, and it does not require further consideration as affecting drainage. The other three heavy storms were as follows:

Three storm periods during period January 1, 1902, to July 1, 1910, with precipitation of over 4 inches.

Date.	Precipitation.	Date.	Precipitation.	Date.	Precipitation.
	Inches.		*Inches.*		*Inches.*
June 25, 1902	0.8	July 16, 1902	0.3	July 5, 1909	1.4
26, 1902		17, 1902	1.3	6, 1909	2.4
27, 1902	.4	18, 1902	1.6	7, 1909	.3
28, 1902	2.5	19, 1902	1.3		
29, 1902	.7	Total	4.5	Total	4.1
Total	4.4				

The Pekin-La Marsh pumping plant, located about 10 miles from the Peoria Weather Bureau station, handled satisfactorily the storm of July, 1909. As this rain was not a sudden shower but a slow, steady rain extending over much of the State, we seem justified in assuming that the Peoria record represents the actual rain at Pekin. Just 11 days before this rain another rainfall of over 1 inch had occurred. It seems fair to conclude that the Pekin plant is able to take care of a 4-inch storm. The only other storm which was plainly and definitely more dangerous than the one just discussed is the one of July. 1902. Preceding the latter by just a week there had been a rain of 2 inches. No other equally severe storm has occurred in 10 years and it does not seem justifiable to make special provision for such a rare occurrence. On several occasions the rainfall on a single day has exceeded the greatest given above, 2.5 inches, but on the whole these other storms have not been so violent as the ones already described. On no occasion has a single day's rainfall exceeded 3 inches.

To see how well the rainfall record at one station might represent the whole region, the record of Peoria was compared with that at other stations, as shown in the following table:

Comparison of records of the Weather Bureau stations at Peoria, Havana, and Griggsville, Ill.

	Peoria.	Havana.	Griggsville.
Average annual rainfall........inches..	35.3	35.5	36.2
Number of months when rainfall exceeded 6 inches between Jan. 1, 1902, and July 1, 1910........	9	....	7
Number of storms equaling 2 inches........	28	....	27
Number of storms equaling 3 inches........	10	....	11
Number of storms equaling 4 inches........	4	....	3

In many cases the individual heavy storms were entirely distinct at the two places, but over a long period the total number and intensity of the various storms are about the same.

To sum up: Since the Pekin plant handled successfully a storm of over 4 inches in July, 1909; also a rainfall for the month of April, 1909. of 7.2 inches; and since the Coal Creek plant handled satisfactorily a rainfall of 6.1 inches for July, 1909, and 6.8 inches for May, 1910, all the experience so far available seems to show that for this region a pumping capacity sufficient to remove one-fourth inch in depth in 24 hours is sufficient.

LOCATION OF PUMPING PLANT.

The pumping plant should be so located that the drainage water may be brought to it with the least expenditure for interior ditches. Where convenient there is some apparent advantage in locating the plant on an arm of the river of ample capacity rather than on the main river channel. The location should be so chosen as to be most easily accessible for the delivery of fuel and for convenience of attendance. In the Pekin-La Marsh district the pumping plant is at the upper end of the district so as to be close to the town of Pekin.

TYPES OF PUMPING MACHINERY.

Since pumps are to be depended upon to remove promptly surplus water, whose presence may endanger a whole crop, it is of the utmost importance that the pumping plant be able to work with certainty and reliability whenever needed.

The annual cost of a pumping plant is made up of three main items: (1) The charge for interest on the original cost of the plant and for depreciation; (2) the cost of fuel; and (3) the cost of labor. Certain general principles concerning the mutual relations of these different items must be understood before taking up the comparison of the different types of machinery available for pumping.

The interest upon the original cost of the plant goes on every year whether the plant is operated much or little. Depreciation also takes place whether the plant is operated or not, and for such installations as are under discussion it probably does not depend much upon the length of time the plants are in operation each year. What amount to allow for depreciation is a difficult matter to decide. The length of time before such machinery will wear out depends chiefly upon the original quality of the installation and the care that is taken of it afterwards. We can not, in general, assume that such machinery will last more than 20 or 25 years. Much of it will be discarded sooner, either because it is outgrown or worn out. With proper care it is probable that such machinery may be made to endure twice as long as it will last if it is carelessly treated. It is customary to include with depreciation an item for repairs. This should be very small during the first few years of the life of a well-constructed plant, but will grow larger as the plant becomes older.

The cost of fuel per year depends to a considerable extent upon the kind of machinery used and also upon the amount of time the plant is run. Whenever a steam plant starts there is a certain consumption of fuel in preparation before starting, and likewise a similar loss after stopping. Hence, since the operation of a pumping plant is very intermittent, the fuel consumption is not strictly proportionate to the time run. The amount of fuel used also depends largely upon the skill of the fireman. An unskillful man may easily use 25 per cent more fuel than is really necessary. Different types of equipment require different amounts of fuel to produce the same result; that is, some types are more economical of fuel than others. The cost of the labor at the pumping plant depends upon the class employed and the length of time it is required.

In general, in a given location, that type of pumping plant will be best which requires the least annual cost, including all the elements enumerated above. To a certain extent, variations in these different elements tend to offset each other. For example, a highly efficient plant from the point of view of fuel economy is complicated and expensive, and hence will have a relatively high charge for interest and depreciation. Likewise, it will require skillful and high-priced attendance, but may, on the other hand, in a large plant, require fewer men. If cheap labor is employed, the coal and repair bills will be increased and the deterioration of the plant will be more rapid. The advantage of fuel economy is relatively more important in locations where fuel is especially high and in a large plant than in a small one, but in any plant it diminishes in importance as the time of running per year decreases or becomes much interrupted.

The above principles have long been regarded as fundamental in the science of mechanical engineering design. Applying them to drainage pumping, since the work will usually be confined to a small portion of the year, since the labor available will be cheap and unskilled, and the other conditions not favorable for careful preservative care of the plant, the fundamental requirements in a drainage pumping plant are reliability and simplicity.

KIND OF PUMP.

The centrifugal pump is the kind most often used for drainage. It is simple, has no valves, and can be obtained in all sizes. Its disadvantages are that it must be primed in starting, it can operate satisfactorily under a particular set of conditions only within a narrow range of speed, and its efficiency when operating under practical conditions is not high. In order to work economically, the speed must be varied as the head under which it operates changes. The size of a centrifugal pump is usually given as the diameter of the suction or discharge opening—that is, a 24-inch pump is one having suction and discharge pipes 24 inches in diameter. Most large pumps are made with a horizontal shaft and are called horizontal pumps. When larger than 24 inches, they frequently have a double suction—that is, water entering at the center on both sides of the impeller. This has the advantage of balancing the side thrust on the impeller and shaft. Without this arrangement some automatic balancing device must be used in connection with the impeller and a collar thrust bearing on the shaft.

The capacity of a pump is usually reckoned by assuming the water to have a velocity of 10 feet a second through the suction and discharge openings of the pump. While it is possible to obtain this discharge by using sufficient power and speed, as the pumps are usually operated in practice the discharge is considerably—often 20 per cent—less than the theoretical rating. In this respect a centrifugal pump differs greatly from engines and boilers. An engine or boiler from any reputable maker can, in an emergency, be made to do 25 per cent more than its rated output—that is, it is said to have an overload capacity of 25 per cent. On the contrary, the rated capacity of a centrifugal pump is just about the limit to which it can be pushed and it has no overload capacity, but usually operates at a lower figure.

Rotary displacement pumps and plunger pumps have been occasionally used for pumping drainage water, but are not well adapted to this use. They may have a very high mechanical efficiency, but their cost more than offsets this advantage. Scoop wheels have been extensively used in England and Holland, and to some extent in this country in Louisiana. They may be made to have a higher efficiency than centrifugal pumps, especially for very low lifts, but they are not so well adapted for a location where the head is subject to wide fluctuations. A full description of the construction and operation of these scoop wheels may be found in a book by W. H. Wheeler.[1] Another publication [2] describes a recent large and successful installation in Holland and gives the results of tests.

SOURCES OF POWER.

Steam is the source of power best for general use. In Illinois soft coal is abundant and cheap for fuel, though in some places crude oil or natural gas may be found more available. A suction gas producer with a gas engine has been tried, but such a plant requires hard coal or coke for fuel, which greatly increases the expense. Furthermore, such a type of plant is not adapted to intermittent working. Electricity is by far the most convenient source of power where it is available, but in general it will be considerably more expensive than using coal to produce steam. Its convenience may perhaps offset its cost, especially for a small plant.

Return tubular, marine, locomotive type, and water-tube boilers have all been used. For a small plant the locomotive type or the simple return tubular boiler is simplest and cheapest. For plants of over 200 horsepower water-tube boilers have decided advantages, though they may cost somewhat more than the simpler fire-tube boilers. The boilers of all large plants should be kept constantly insured by some reliable boiler-insurance company.

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[1] The Drainage of Fens and Low Lands by Gravitation and Steam Power. London and New York, 1888.

[2] Engin. News, 63 (1910), No. 20, p. 581.

KIND OF ENGINE.

Either vertical or horizontal engines may be used. When possible, it is best to have the pump directly connected to the engine. This is usually not feasible for a pump smaller than the 24-inch size, because such a pump would require too high a speed of the engine. In this case the pump must be driven by a belt or a rope. The engine should be condensing and, if large, should be compound. A high-speed automatic engine is more difficult to operate with inexperienced labor than a slow-speed engine, but it has the advantage of being smaller and lighter for the same power than the slow-speed engine of the Corliss or some similar type. In general, however, the high-speed engine is not as economical of steam as the slow-speed type. The engine should be provided with a governor able to keep it from racing if the entire load is suddenly removed. The engine should be adjustable for a considerable range of speed, should be able to carry a considerable overload, and should work as economically as possible through a wide range of load. As will be explained more fully below, it is especially desirable that an engine for this work should be capable of very flexible operation.

AUXILIARIES.

The plant will require the usual auxiliaries. A surface condenser will furnish pure feed water, but some form of jet condenser is simpler and cheaper. For priming the pumps a steam ejector is the simplest arrangement, though an air pump may be used. Separators and traps, filters, and heaters should be used as needed for safe and economical operation. Piping and boilers should be well covered to reduce as much as possible the amount of radiation and condensation of steam.

In large plants boilers, engines, and pumps should all be divided into two or more equal-sized units, so arranged that they can, when necessary, be operated independently, and the auxiliaries should be installed in duplicate.

CALCULATION OF THE SIZE OF PUMPING PLANT.

To illustrate the method of determining the size of machinery to be installed in a pumping plant, the calculation will be made for a district of 10,000 acres. To remove a depth of water of one-fourth inch over the whole district in 24 hours will require a capacity of 105 cubic feet per second. For such a district it will be best to use two separate pumps, which should be identical in size. A 30-inch pump will be rated at about 49 cubic feet per second; a 32-inch pump at about 56 cubic feet per second; and a 36-inch pump at about

71 cubic feet per second. In this case it would be best to use two 32-inch pumps, which would seem to have a slight margin of excess capacity. However, since pumps of this style so frequently fail to have the capacity assumed, they should be taken only under the guaranty of the manufacturer, and subject to a thorough test after they are installed. The pumps will need to be run at about 200 revolutions per minute and hence may be directly connected to two separate engines.

Assume that the difference between the river-surface level outside the district and the desired ground-water level within the district will vary from a possible maximum of 20 feet during spring floods to nothing in the late summer. The machinery must have sufficient power to pump against the highest head, although much of the time it will run against a lower head. This is a disadvantage so far as the efficiency of the machinery is concerned, because every engine runs most efficiently at about its rated capacity, and if it is either overloaded or underloaded its efficiency is reduced. The actual head against which the pumps must force the water, sometimes called the dynamic head or the hydraulic head, is always greater than the difference in water level as described above, which is called the static head. This increase is due to the friction of the water in the suction and discharge pipes and the so-called velocity head—that is, the head necessary to start the water into motion in the pipes. The friction in pipes carrying water at a high velocity is greatly affected by the kind of pipe used and the smoothness of the interior surface, and hence can not be predicted with certainty. For a velocity of 8 feet a second, the friction in 200 feet of 48-inch pipe would probably amount to 2 feet of head, and in a 24-inch pipe to at least 6 feet of head. A bend of 90° adds probably a foot to the friction head. The velocity head amounts to about 1 foot, and if the water passes around a sharp edge in entering the suction pipe there is probably a loss of another foot of head. To be safe, then, we should assume the addition of at least 6 feet to the static head to give the head on the pump. Another small amount might be added to the lift, on account of the lowering of the water level in the supply ditch when the pumps are being operated. But it is probably better to ignore this last addition and assume that during the short time when the river is at maximum flood stage the water level in the district will not be pumped down quite to its normal level rather than to provide extra capacity for the very short and infrequent periods of maximum river floods.

With a total head of 26 feet the hydraulic horsepower is calculated by multiplying together the lift—26 feet—the number of cubic feet of water per second—105—the weight of 1 cubic foot of water—

62.5 pounds—and dividing by 550. In this case the result is 310. The power required of the engine will be greater than this amount, depending upon the efficiency of the pumps, which for these conditions should be at least 60 or 70 per cent. For this case probably manufacturers would be willing to guarantee an efficiency under test of 70 per cent. Accordingly the maximum brake horsepower required of the engines would be 440. Engines suitable for this work should be able to carry continuously an overload of 25 per cent without an increase of speed and without a great loss in steam economy; hence, if 440 horsepower puts this overload on the engines, their normal rating would be 350 brake horsepower. They should develop this power at the speed at which the pump has the best efficiency for a static lift of 15 feet or a dynamic lift of 21 feet. When the pumps operate at the maximum lift, their speed should be increased in order to maintain the discharge and the efficiency of the pumps, and the engines should be adjustable and so constructed as to run safely at the higher speed. Since increasing the speed of itself increases the power developed by the engines, this gives a margin of safety in the capacity of the engines. If two separate engines and pumps are used, each engine should have a brake horsepower of 175. Its indicated horsepower will be from 10 to 20 per cent greater. An engine should run fairly economically down to three-fourths of its rating. These units, then, would be economical of fuel down to a static lift of 10 feet. But when the lift falls below 5 or 6 feet, the steam used by the engines will be much increased in proportion to the useful work actually performed in lifting the water. This disadvantage is not very important, however, because the amount of water to be lifted under such conditions is small.

The boiler capacity required would depend upon the particular engines used, upon the number and kind of auxiliaries, and upon the quality of coal to be used. For a plant of this kind, however, the nominal boiler horsepower should be at least as large as the rated engine horsepower. The boilers must have a capacity amply sufficient to supply safely all the steam needed by the engines when operating at their maximum overload. This may be secured by additional boilers or by forcing the boilers when necessary through appliances for producing an artificial draft. In general, large engines of the best types require less steam per horsepower than smaller ones. In a very large plant the nominal boiler horsepower may be less than the engine horsepower.

In designing such a plant all the elements must be carefully calculated to secure in each the necessary maximum capacity. It is especially needful that the auxiliaries be large enough. A deficiency in some single comparatively slight but essential element may hinder the operation of the whole plant. Durability and reliability in workmanship and materials may be secured to some extent by specifying that the boiler shall be capable of operating at a higher pressure than its regular working pressure, and that the engines shall be able to run with higher steam pressures and at higher speeds than the normal. Descriptions of a large number of pumping plants and the results of tests are given in detail in a bulletin of the office.[1]

BUILDINGS AND FOUNDATIONS.

The pumping plant should be inclosed in a substantial and durable building. The foundations of the building, and especially of the machinery, should be prepared with great care. Usually the soil conditions are not good, so that piling must be driven under all the foundations for the machinery. The piling must be made ample to secure firm and rigid support for all the machinery so that there may be no subsequent settlement.

ARRANGEMENT OF SUCTION AND DISCHARGE PIPING.

Proper arrangement of the suction and discharge pipes is very important for the economical and reliable operation of the plant. A sketch plan of the Coal Creek drainage and levee district pumping plant, showing the general arrangement of the pumps and pipes with regard to the main ditch and the levee, is given as figure 2. The pipes should be as direct and straight as possible. All bends should be of long radius and the interior of the pipe should be as smooth as

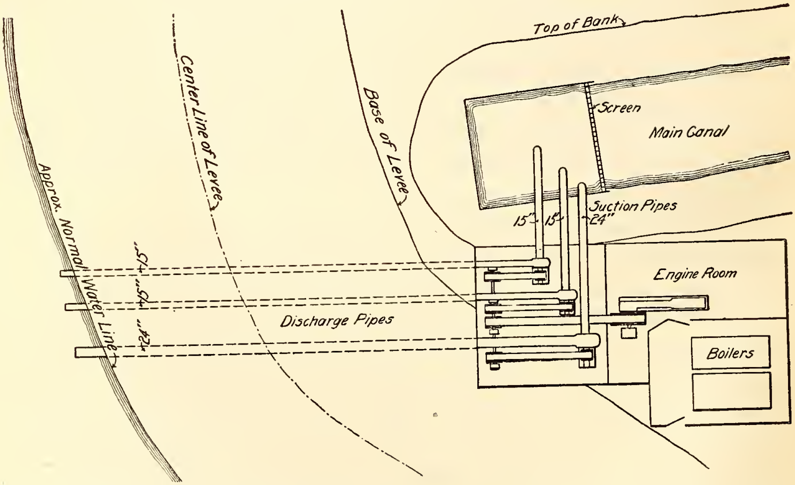

FIG. 2.—Sketch plan of pumping plant, Coal Creek drainage and levee district, Illinois.

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[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 183.

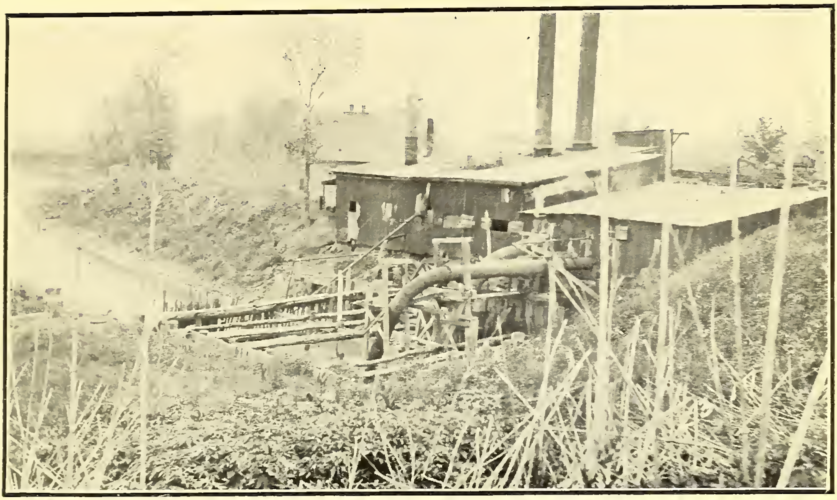

FIG. 1.—PUMPING PLANT, COAL CREEK DRAINAGE AND LEVEE DISTRICT.

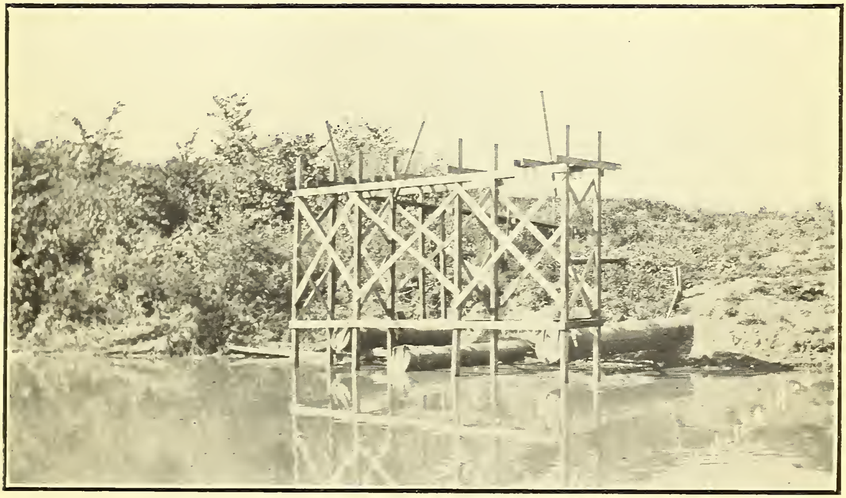

FIG. 2.—ENDS OF OUTLET PIPES, COAL CREEK DRAINAGE AND LEVEE DISTRICT.

practicable in order that the lost work due to friction may be small. Since the head consumed in overcoming friction varies as the square of the velocity, the larger the piping the less the friction loss. Where the piping is long this is the more important. The piping should be made large enough to reduce the velocity in the pipe down to as near 5 feet per second as practicable. All changes in size and direction of the piping should be gradual, and at no point should the water be permitted to flow around a sharp corner.

The suction pit should be carried to a greater depth than the main canal, even though this results in some danger of excessive seepage and of the opening of springs or boils through the lower layers of soil from the river when the suction pit is close to the river bank. This has been a frequent source of difficulty in pumping plants, and on this account the pipes to and from the pumps should be made longer than would otherwise be necessary. In the smaller plants the lower part of the suction pipe is usually vertical or nearly vertical, and has above the vertical portion a right-angle turn connecting to a horizontal piece of pipe leading to the pump. Such an arrangement is illustrated by figure 1 of Plate III, a rear view of the pumping plant of the Coal Creek drainage and levee district showing the suction pipes and the suction bay. Where this arrangement is used the edge of the lower end of the pipe is made in a horizontal plane. This end should also be expanded so as to provide for a gradual contraction of the stream of entering water. The curvature of the expanded end may be relatively abrupt, but should be smooth so that the water may not flow swiftly past any sharp edge or angle. In general, in contracting a stream there is no loss of head, even if the reductions in cross section are comparatively sudden, so long as the surfaces are smooth and curved without any sharp angles. On the other hand, in expanding the cross section of a stream so as to reduce its velocity, the changes must be very gradual or there will be loss of energy due to the impact of the rapidly moving stream striking against the more slowly moving mass of water.

The horizontal edge of the entrance to the suction pipe must be at least as low as the lowest level to which the water is to be reduced in the main ditch, and below this edge there should be a clear distance to the bottom of the suction pit equal to one or one and a half times the diameter of the suction pipe. It would be better if the end of the pipe were a foot lower than the level mentioned above. If the entrance to the suction pipe is expanded to such a degree that the velocity of the incoming water past the edge of the pipe is not more than 2 feet per second, the water level can be drawn down to the end of the suction pipe without trouble from sucking air. Without such expansion, while the level of the water is still a considerable distance above the end of the pipe, much air will be drawn into the pump, with a consequent waste of power and danger of stopping the pump. Neglect to provide ample water way around the entrance to the suction pipe has been a source of much annoyance to pumping plants.

Though a suction pipe with a vertical portion at its lower end is probably most easily given a rigid support in the suction pit, a better arrangement for a large plant would be to place the suction pipe on a uniform slope from the pump to its open lower end in the suction pit. This slope should be flat enough so that the pipe can be supported rigidly. The suction pit should be of concrete throughout, reenforced where necessary, shaped so as to form a suitable gradually curved entrance to the suction pipe, and provided at its outer end with a steel screen and with vertical ways for inserting stop planks. The gate openings and the screen openings should be of such size that the velocity through them under normal conditions would not be more than 1 foot per second. In order that the suction lift may be kept low, the pump should be set as low as is consistent with securing good foundations, ease of installation, and safety after installation. The suction pipe must be perfectly airtight and strong enough not to collapse under the greatest suction that will be put upon it.

The discharge pipe should be gradually expanded immediately after leaving the pump so as to reduce the velocity to as near 5 feet per second as seems practicable. If the velocity is not lowered to this amount the outlet should be expanded an equivalent amount. Practice is not uniform as to the best method of preventing water from flowing back through the pipes into the district from the river when the pumps are not operating. Some prefer to carry the discharge pipe through the levee above high-water line and then down, with its end opening below low water, so as to secure a water seal. This is necessary in order that the pipe may act like a siphon and that hence the head on the pump may be only the difference in level between the water in the canal and the water in the river. In this case the pipe must have an opening of ample size at the highest point for use in priming the pump. This is opened to prevent water flowing back by siphon action when the pump is stopped. Others prefer to carry the discharge pipe from the pump through the levee on a level. This necessitates the installation of a gate valve in the pipe next the pump. If the pipe is not over 2 feet in diameter a flap valve may be used on its outer end, but such a valve is never entirely reliable and certain in its operation. A gate valve, if such is used, must be of a slow-closing type, as it is very dangerous to the plant to close such a large valve quickly. The outlet end of the discharge pipe must have an adequate masonry protection against river wash and against undercutting by the pump discharge.

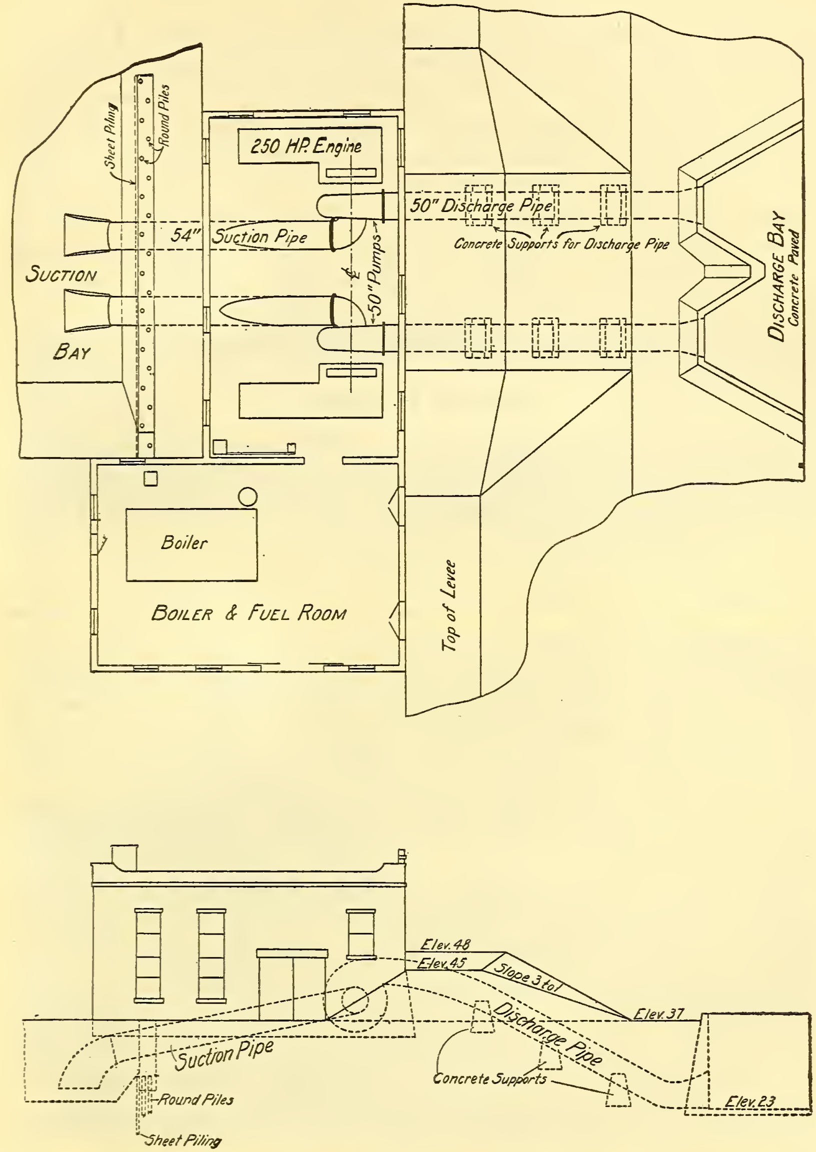

FIG. 3.—Plan and elevation of pumping plant, Louisa-Des Moines drainage district No. 4, Iowa.

The Louisa-Des Moines drainage district No. 4, in Louisa and Des Moines Counties, Iowa, has a well-arranged pumping plant of large size. Figure 3 gives the plan and elevation, showing well the arrangement of suction and discharge pipes. Figure 2 of Plate III shows the flap valves on the outer ends of the discharge pipes of the Coal Creek district. The pipes are above low water in the river and so are exposed, as shown, whenever the river is low. Plates IV and V are views of the Louisa-Des Moines district pumping station. Figure 1 of Plate IV is a view from outside the levee, showing the front of the building and the discharge bay. Figure 2 of the same plate is a view of the engine-room giving a good idea of the size of the 50-inch centrifugal pumps, each of which is direct-connected with a tandem compound condensing engine of 250 horsepower. Plate V shows in figure 1 the rear of the building, with the levee beyond, and in figure 2 a near view of suction bay showing the enlarged ends of the suction pipes. When the latter photograph was taken, the wall about the bay had not been completed. The building is of fireproof construction.

COST OF PUMPING.

The cost of installing a pumping plant will depend upon its size, location, the kinds of machines adopted, and the market conditions at the time, so that it is impossible to determine a definite normal price; probably the entire plant, including pumps, engines, and boilers, can be installed and a suitable building provided in most places for not over $90 per nominal horsepower. Under favorable circumstances the cost may be materially lower. For the plant used as an illustration, above 1 horsepower was required for each 30 acres. Hence, the cost of the pumping plant complete should not exceed $3 per acre. With interest at 6 per cent and an allowance of 4 per cent for depreciation, the total fixed charges would amount to 10 per cent per annum or 30 cents per acre of land per year. This charge is, of course, constant every year, whether the plant runs much or little, or not at all.

The annual cost of operation will depend upon how much water the pump raises during the year. Continuing the use of the same illustration as before, with liberal assumptions so as to be on the safe side, to remove during the year a depth of 1.5 feet of water over the district of 10,000 acres against an average static head of 16 feet will probably require 1,700 tons of coal which, at a cost of $2.50 per ton, would amount to $4,250. One man might well be employed to take care of the plant throughout the year at $100 a month; the expenditure for all other labor probably need not exceed $800. This would make a total of $2,000 per year for labor. The total cost of operation, then, might approximate $6,250, or about 60 cents per acre, which with the charge for interest and depreciation would make the total annual charge 90 cents per acre. This is a liberal estimate and in dry years would be much reduced.

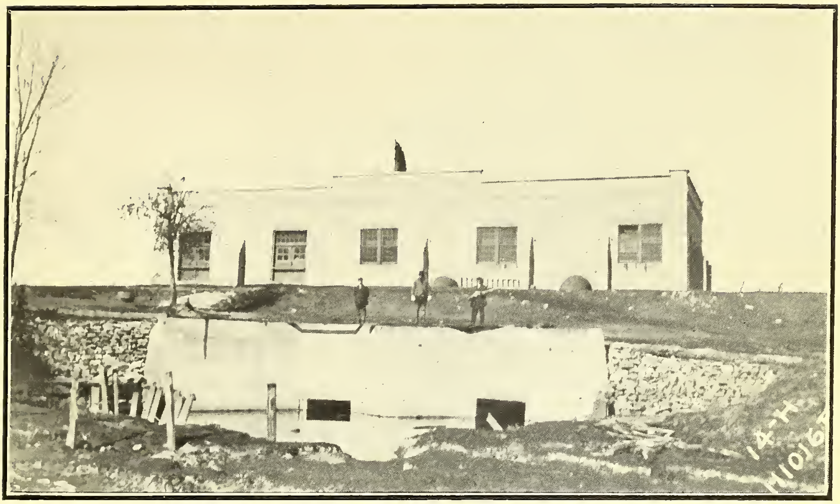

FIG. 1.—PUMPING PLANT AND DISCHARGE BAY, LOUISA-DES MOINES DRAINAGE DISTRICT.

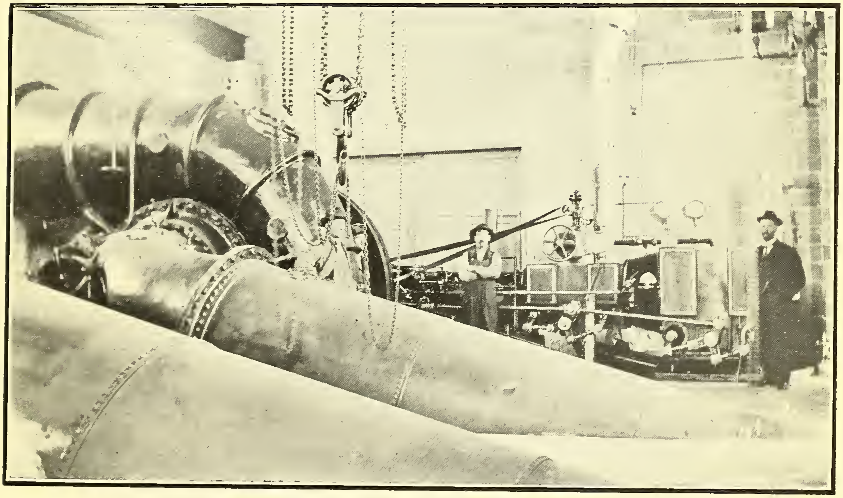

FIG. 2.—ENGINE ROOM, LOUISA-DES MOINES DRAINAGE DISTRICT.

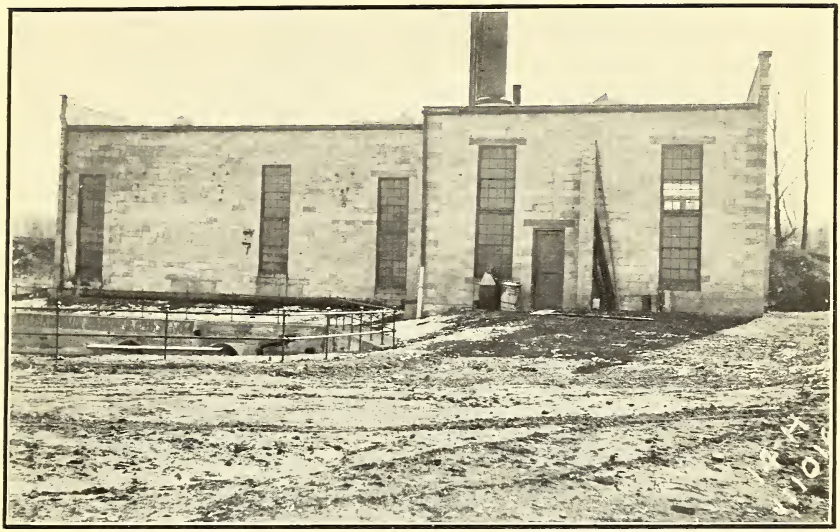

FIG. 1.—REAR OF PUMPING PLANT, LOUISA-DES MOINES DRAINAGE DISTRICT.

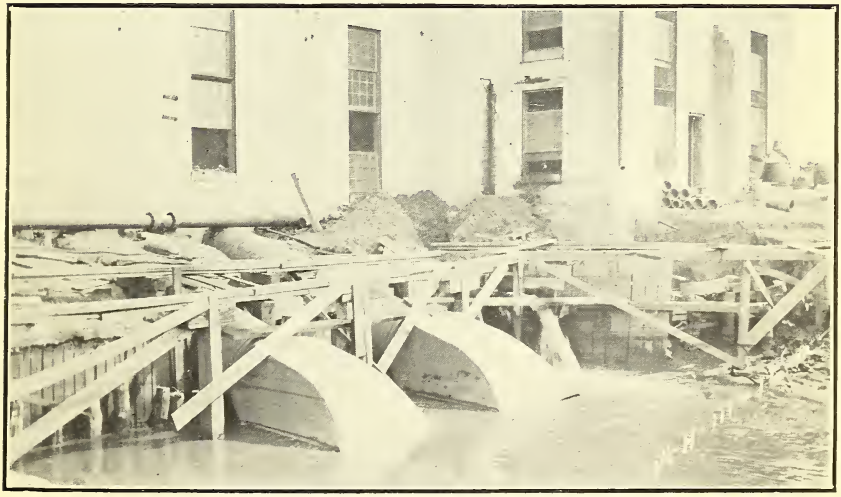

FIG. 2.—SUCTION BAY, LOUISA-DES MOINES DRAINAGE DISTRICT.

Careful management will do much to reduce the operating expense. Without expert supervision the cost of running when left to ignorant workmen may greatly exceed the estimate given above. To discover possible sources of waste, a complete daily record of the operation of the plant should be maintained. From such data it may be possible to study out improved methods of operation or ways of securing greater economy. Without such a record it is impossible for anyone to tell in what particulars the operation of the plant may be susceptible of improvement. Such a record should show the time of starting and stopping the pumps each day, the height of the water level within and without the district, the speed of the pumps or engines, and the amount of fuel consumed. It should set forth all happenings of importance in the operation of the plant, and may be kept in a form similar to the following:

Form for daily pumping records.

Date....................................

Hour.	Ditch gauge.	River gauge.	Lift.	Speed of pump.	Steam pressure.	Rainfall.	Remarks.
	Feet.	*Feet.*	*Feet.*	*R. P. M.*	*Pounds.*	*Inches.*	

One page should be used for each day. The gauges should be read before the pumps are started, again as soon as the ditch level has reached a fairly steady state, perhaps one-half hour after starting the pumps, and at several additional times during the day. If more than one pump is in operation the speed of each should be recorded. All additional matters should be recorded in the Remarks column. The amount of fuel consumed each day should be determined, if feasible, and recorded. An accurate rainfall record should be kept at every pumping plant.

The expenses of operating a pumping plant should be divided under the following headings: Fuel; labor; supplies, such as lubricating oil, waste, etc.; repairs; and superintendence. These expenses should be totaled for each month and for the whole season.

The engineer in charge of the plans for a pumping district should do the utmost to impress upon the district authorities the relative importance of the fixed interest and depreciation charges, the necessity of proper attention to the care and maintenance of the plant, especially during the part of the year when it is not in operation, and the need of proper records and attention for the economical operation of the plant. The keeping of proper records for a pumping plant is as important as bookkeeping for a merchant. In default of previous knowledge, people must be taught these things. They may find experience a dear teacher.

RELATIVE BENEFITS OF DRAINAGE BY PUMPING.

Experience on the Illinois River shows that the first cost of the general district drainage improvements, including levees, ditches, and pumping plant, has varied between $15 and $30 an acre. As all the cheapest projects have now been developed, however, there is a growing tendency to undertake the reclamation of more expensive districts in which the cost may exceed by $10 or $20 per acre the amount just stated. The cost of clearing the land and field drainage may be between $5 and $20 an acre. Hence, in places the total cost for putting the land into profitable productive condition may be as high as $50 per acre. Such land is then worth from $100 to $125 per acre, according to the present value of the contiguous uplands.

The best way for one unfamiliar with the conditions existing in pumping districts to become informed on the subject is to visit and inspect thoroughly one or more such districts. The following list contains most of those with much experience in pumping. Following the name of the district is given its size, the date when pumping was first begun, and the name and address of some one of its officers who can give information concerning it.

Pekin-La Marsh district; 2,800 acres; about 1890; C. L. Velde, Pekin, Ill.

Rhodes district; 3,000 acres; 1900; Judge Williams, Havana, Ill.

Langellier district; 2,200 acres; 1907; A. L. Langellier, Havana, Ill.

Coal Creek district; 6,700 acres; 1898; Jesse Lowe, Beardstown, Ill.

Meredosia district; 3,500 acres; 1904; John Rogge, Meredosia, Ill.

Magee Creek district; 12,000 acres; January, 1909; ———.

Big Swan district; 12,000 acres; 1908; Charles Condit, Winchester, Ill.

Hillview district; 12,400 acres; January, 1909; Louis Lowenstein, Hillview, Ill.

Fairbanks district, near Hillview; 12,000 acres; 1910; W. A. Hubbard, Carrollton, Ill.

Nutwood district; 10,800 acres; February 1, 1910; Steven M. Reddish, Jerseyville, Ill.

Bay Island district; 22,000 acres; March, 1910; M. F. Prouty, New Boston, Ill.

Louisa-Des Moines district, No. 4; 17,000 acres; May, 1909; ———, Oakville, Iowa.

South River district; 12,000 acres; 1910; ———, Hannibal, Mo.

SUMMARY.

The reclamation for agricultural purposes of river bottom lands lying so low that they are subject to serious injury by overflow has been proved by experience in Europe and in this country to be feasible and profitable when carried out by means of a system of protective levees supplemented by interior drainage ditches and a pumping plant to remove excessive precipitation which may fall within the district.

Numerous tracts in units of from 5,000 to 20,000 acres have been thus reclaimed along the Illinois River and on both sides of the Mississippi in the States of Illinois, Iowa, and Missouri. In some districts the cost of the general drainage improvements, including levees, ditches, and pumping plant, has been as high as $30 per acre. This method of reclamation may be expected to be extended constantly to new localities as agricultural land becomes more valuable.

The design and construction of the levees, ditches, and pumping plant require a considerable degree of engineering ability. Poor design may result either in a system so inadequate for its purpose as to yield a benefit to the land insufficient to make the undertaking profitable, or it may lead to an expenditure for construction greatly in excess of the amount that could have been made to suffice. In general, the inexperienced tend to underestimate greatly the extent and expense of the work required in such reclamation.

The levees must originally be made of such height and thickness as to afford ample strength and they must also be given careful subsequent attention to secure proper maintenance. The internal drainage ditches should be deep enough to keep the ground water level at least 3 feet below the surface and their capacity should be sufficient to discharge heavy rains freely to the pumping station. Streams entering the district from higher ground should be diverted around the levees where such a plan is feasible.

The pumping plant should have a capacity sufficient to remove as a minimum amount in 24 hours a quantity of water sufficient to cover the entire district to a depth of one-fourth inch. The capacity should be greater in situations of heavy rainfall and where the run-off of rolling land is received in the district.

The pumping machinery should be so arranged as to reduce to a minimum the work of disposing of the surplus water, and it should be chosen with especial regard to economy and efficiency in operation. Where large fluctuations in the river level are to be expected, the machinery must be sufficiently large to operate at the maximum head, and at the same time must be as efficient as practicable for more moderate heads.

The operation and supervision of the pumping machinery must be given careful attention with a view to securing the greatest economy in operation and careful preservation throughout the year. This requires the use of reliable skilled attendants. Full records of the operation of the pumping plant should be maintained, as well as detailed classification of expenditures, so that those in charge can determine at all times whether the operation of the plant is the most economical that may be possible in securing the results desired from the plant.

Where practicable, gravity outlet sluiceways should be installed in connection with a pumping plant for use during times of low water outside of the drainage district.

When properly designed and operated drainage pumping plants prove highly profitable for the reclamation of wet lands in regions where agricultural land is sufficiently valuable.

[Bull. 243]

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